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Hydrogenated Amorphous Silicon Thin-Film Disk Resonators

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Abstract

Microelectromechanical (MEMS) structures consisting of surface micromachined disk resonators of phosphorous-doped hydrogenated amorphous silicon (n-a-Si:H) deposited by radiofrequency plasma enhanced chemical vapour deposition (RF-PECVD) were fabricated and characterized. Quality factors up to 10^4 in vacuum were measured for disk resonators operating at frequencies between 0.1 and 10 MHz. The metallized structures were actuated with electrostatic force by radially placed electrodes. Finite element simulations were used to identify the type of vibrational modes present and show good agreement with measured values. Resonator geometry and ambient pressure were varied to attain a generalized understanding of the RF performance. Higher harmonic modes show increasing quality factors which bears great potential when designing sensors for operation in dissipative media.

Keywords: RF MEMS; resonators; amorphous silicon

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1. Introduction

Due to high quality factor, Q, high resonance frequencies, f_{res}, and small masses, m, MEMS resonators are attractive device elements for high frequency sensors. RF applications as oscillators have also been the focus of much interest due to their potential as alternative to quartz crystals as frequency reference element [1]. Resonator based mass sensors have been proposed sensors for label free biodetection applications [2]. The electromechanical response of the devices is influenced by several physical parameters such as geometrical dimensions, mass, internal stresses, and ambient pressure and viscosity [3]. For the generality of applications, high resonant frequencies and high quality factors result in

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increased sensitivity. Design optimization of resonators for operation at ambient pressure or in liquid environments is of current great interest, since quality factors of, e.g., standard flexural resonators are strongly reduced in dissipative media [4].

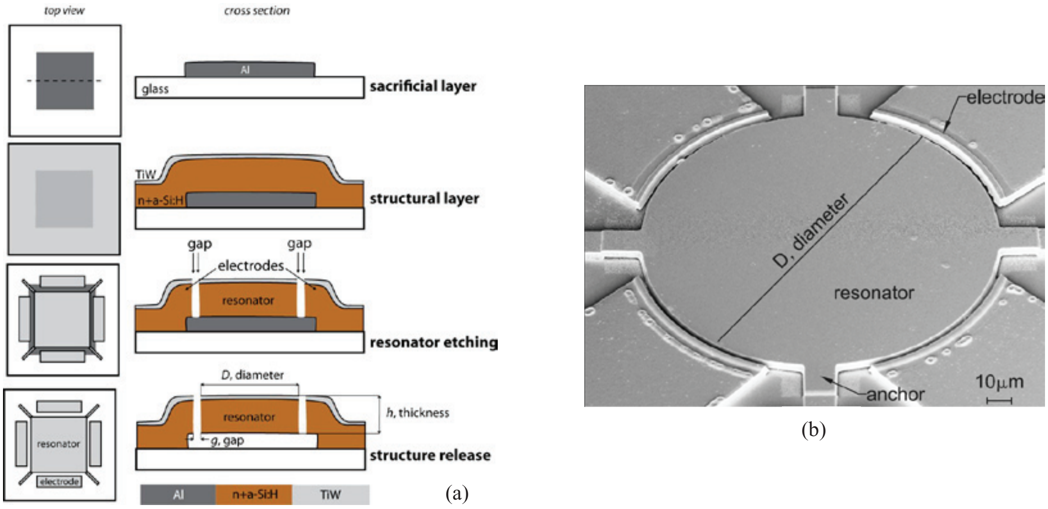
Thin-film technologies present advantages that result from the low-temperatures used in most thin-film processes, which allow the use of a wide variety of substrates such as glass of polymer sheets. Another important feature is that the thin-film properties (mechanical, optoelectronical, and chemical) can be tuned by adjusting the deposition conditions. Thin-film MEMS devices based on a-Si:H have been previously reported [5,6].

This work presents thin-film MEMS electrostatic disk microresonators fabricated on glass substrates that can be used in applications such as RF filters, oscillators, or sensitive mass detectors.

2. Experimental Procedures

Fig. 1 (a) summarizes the fabrication process for bulk resonators with 2 pairs of orthogonally located anchor stems with lateral electrodes. A sacrificial layer of 1 µm thick Al is used and a structural layer of n-a-Si:H is deposited on top by RF plasma-enhanced chemical vapour deposition (PECVD) with 5 W power and 100 mTorr pressure using a gas mixture of silane, hydrogen and phosphine. After the final metallization with TiW, the structures are patterned by reactive ion etching (RIE), resulting in reasonably vertical sidewalls. In the final step, a wet etchant is used to selectively remove the sacrificial layer and release the structures. Typical dimensions are diameter, *D*, of 50-300 µm; thickness, *h*, of 3 µm; and gap distance, *g*, of 2 µm. Fig. 1 (b) shows a scanning electron microscope (SEM) image of a device.

The structures are electrostatically actuated by applying a voltage with DC and AC components between the disk and the electrode. The resulting deflection is detected using an optical method that has been described previously [5]. The resonance frequencies of the resonators, which occur in the MHz range, were measured at ambient pressure and vacuum conditions, as a function of the disk diameter.



(a)

(b)

Fig. 1. (a) Fabrication sequence of n^+-a-Si:H bulk resonators on glass substrates; (b) SEM micrograph of a 100 µm diameter disk resonator with 4 lateral electrodes.

3. Experimental Results and Discussion

3.1. FE analysis and frequency response

Attribution of the vibrational modes related to the resonance peaks detected is made using finite-element (FE) mechanical modeling of the MEMS structures. FE simulations enabled the identification of the desired bulk modes and also flexural membrane-like modes starting at lower frequencies. The detected resonance peaks showed good agreement with simulated values corresponding to fundamental membrane modes with zero, one and two diameters of nodal displacement (see Fig. 2). Taking a diameter series of microresonators, the flexural nature of these modes is also evident, since the frequency follows $1/D^2$ dependence (see Fig. 3(a)).

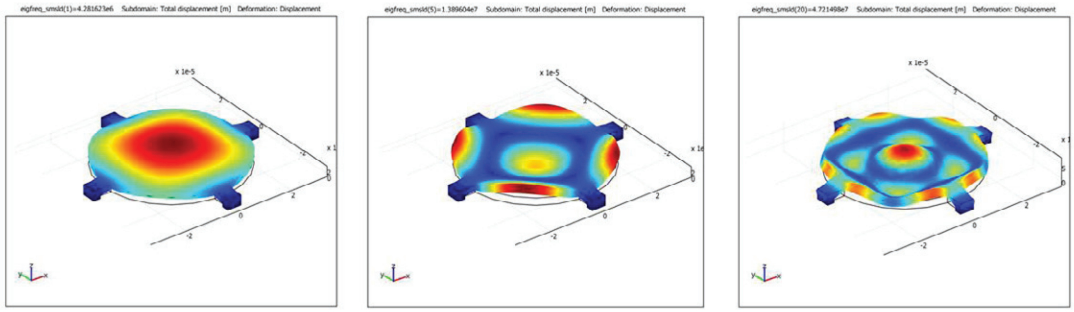


Fig. 2. FEM simulated mode shapes for modes (01), (02) and (03) for a resonator disk.

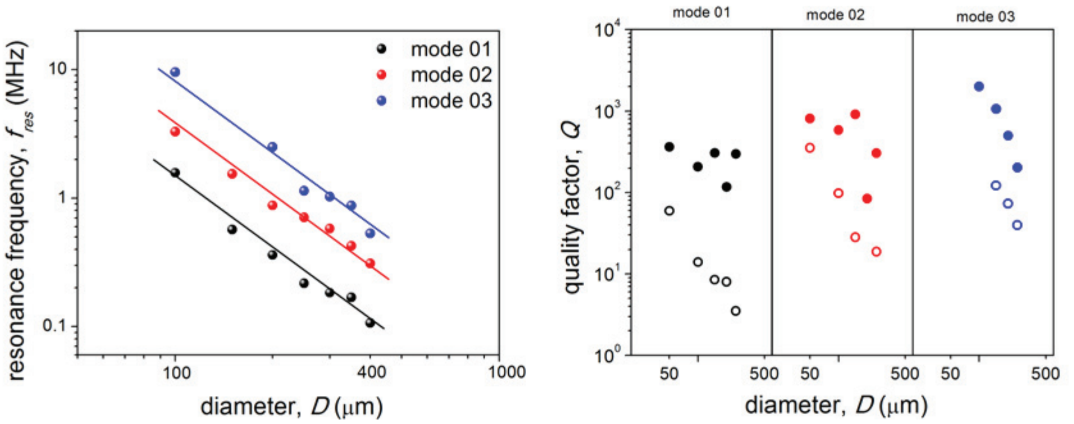
3.2. Quality factor

Quality factors up to 10^4 were measured for the detected resonance peaks (see Fig. 3 (b)). This value is close to the thermoelastic damping limit, controlled by the material properties and the device thickness [7]. When the same vibrational mode is measured, the quality factors were found to increase with resonance frequency (or, correspondingly, to decrease with increasing disk diameter).

The influence of pressure on the quality factor for the different vibrational modes observed is also shown in Fig. 3 (b). When the pressure is decreased from ~10^3 Torr to vacuum conditions (~10^{-5}Torr), there is a strong increase in Q, which corresponds to a sharpening of the resonance peak. An increased quality factor with increasing resonance frequency is also observed in the case of vibration in air. Results also suggest that as the mode number increases, not only the quality factor is higher, but that the difference between the Q values in air and vacuum narrows.

4. Conclusions

This work reports on the dynamic response of disk microresonators using n-a-Si:H thin films fabricated on glass substrates. The fabricated MEMS devices were measured in vacuum and air with resonance frequencies up to 10 MHz and quality factors up to 10^4. The microresonators presented in this work have good potential for high-Q sensors when operated in air and the results suggest that higher harmonics of the fundamental modes show promise for higher sensitivity.



(a)

Fig. 3. (a) Resonance frequencies of modes (01), (02) and (03) from disk resonators measured as a function of the resonator diameter, in the intrinsic dissipation regime; (b) Quality factor measured in vacuum conditions (closed circles) and ambient pressure (open circles) .

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